

Diffraction Measurements from Zeus



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1. **General Introduction**
2. **Measurements in Photoproduction ('94 data)**
3. **Preliminary results in DIS ('94 data)**

5th International Workshop
on
Deep Inelastic Scattering and QCD
Chicago, Illinois, USA
14-18 April 1997

Definition of Diffraction

"The probability there are no hadrons in a sufficiently large gap of rapidity Δy goes as $\exp(-a\Delta y)$ where a depends on the quantum numbers carried by the gap"

R. Feynman.

$$\text{pQCD: } a \propto \omega = N_c \int_{Q_0^2}^{Q_{max}^2} \frac{\alpha_s(k_t^2)}{k_t^2 \pi} dk_t^2$$

$$P(\Delta y) \propto e^{-\omega \Delta y}$$

$$\text{Regge: } a = 2(1 - \alpha_j)$$

$$\alpha_\pi \sim 0 \quad \implies \quad P(\Delta y) \sim e^{-2\Delta y}$$

$$\alpha_R \sim 0.5 \quad \implies \quad P(\Delta y) \sim e^{-\Delta y}$$

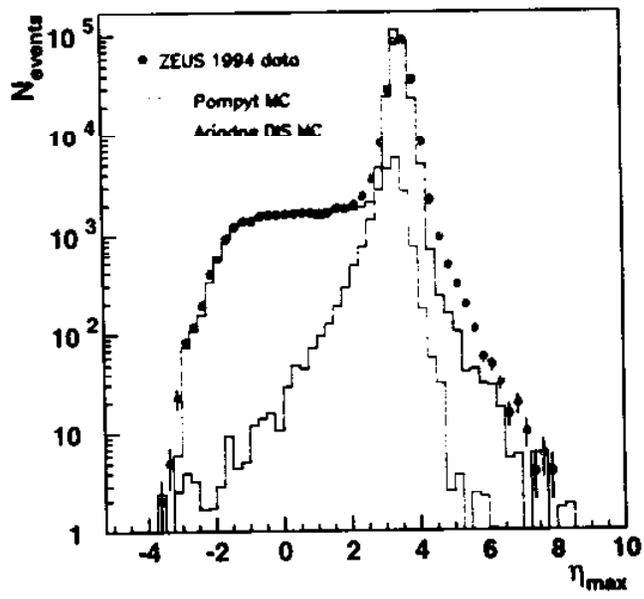
$$\alpha_P \sim 1 \quad \implies \quad P(\Delta y) \sim e^0$$

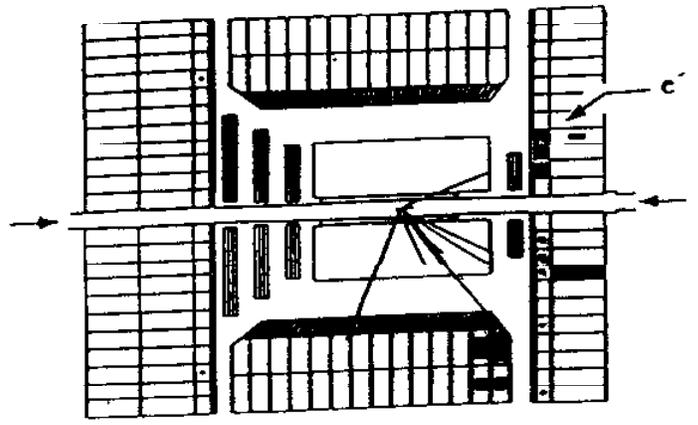
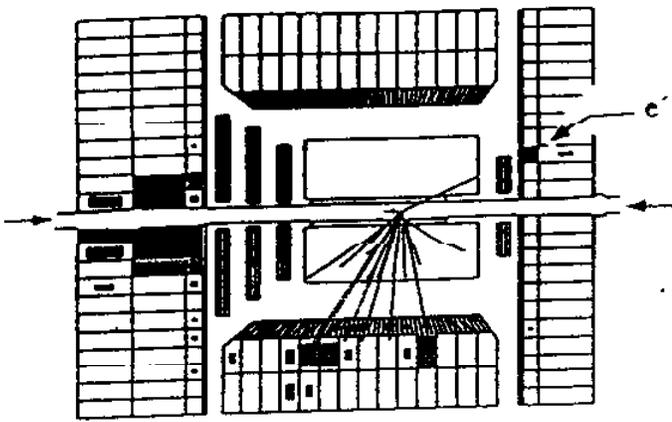


"A process is diffractive if and only if there is a large rapidity gap in the final-state phase space which is not exponentially suppressed"

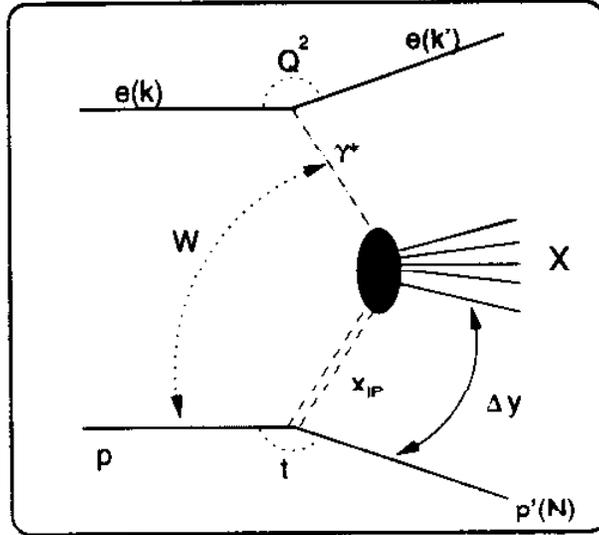
J.D. Bjorken.

ZEUS 1994





Kinematics of Diffraction



Standard kinematic variables for Deep-Inelastic Scattering:

$$Q^2 = -q^2, \quad x_{bj} = \frac{Q^2}{2q \cdot p}, \quad y = \frac{q \cdot p}{k \cdot p}, \quad W^2 = (q + p)^2$$

Diffractive Variables:

$$M_x = \sqrt{(E^2 - \vec{p}^2)}, \quad t = (p - p')^2$$

$$\beta = \frac{Q^2}{2q \cdot (p - p')} \simeq \frac{Q^2}{Q^2 + M_x^2}$$

$$x_P = \frac{q \cdot (p - p')}{q \cdot p} \simeq \frac{Q^2 + M_x^2}{Q^2 + W^2}$$

such that $x_{bj} = \beta \cdot x_P$.

Motivation

- Pomeron trajectory: $\alpha_p(t) = \alpha_p(0) + \alpha' t$

$$\sigma_{tot} \sim W^{2(\alpha_p(0)-1)}$$

- Diffractive scattering

$$\frac{d\sigma}{dt dM_x^2} \sim W^{2 \cdot (2\alpha_p(0)-2)} \left(\frac{1}{M_x^2}\right)^{\alpha_p(0)} e^{b_{eff} t}$$

- Soft interactions

$$\sigma_{tot}(\gamma p) \sim (W^2)^{0.08}, \quad \alpha_p(0) \sim 1.08$$

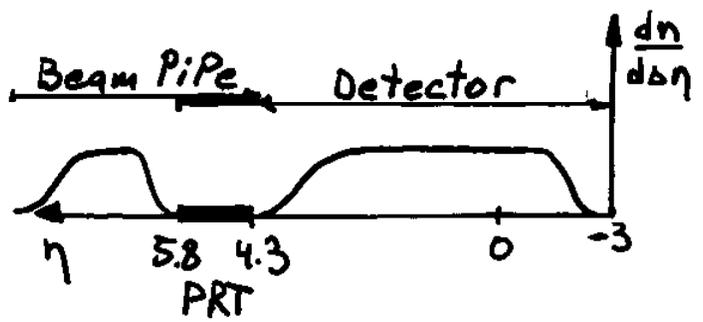
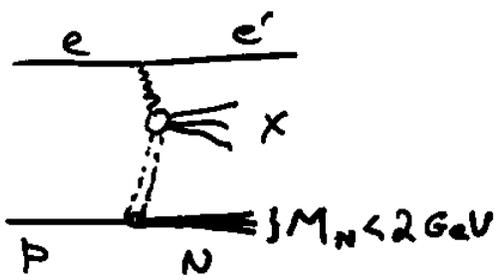
- DIS

$$\sigma_{tot}(\gamma^* p) \sim (W^2)^{0.2 \div 0.4}, \quad \alpha_p(0) \sim 1.2 \div 1.4$$

- α_p in diffraction

in tagged photoproduction ($Q^2 \sim 0$) measure $\frac{1}{M_x^2}$ distribution at fixed W .

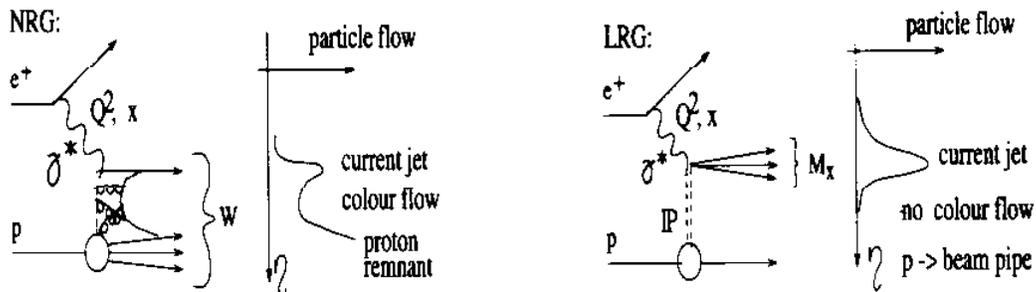
In DIS measure W dependence at fixed M_x .



Methods used at ZEUS

Rapidity-gap method:

Define $\eta = -\ln(\tan(\theta/2))$



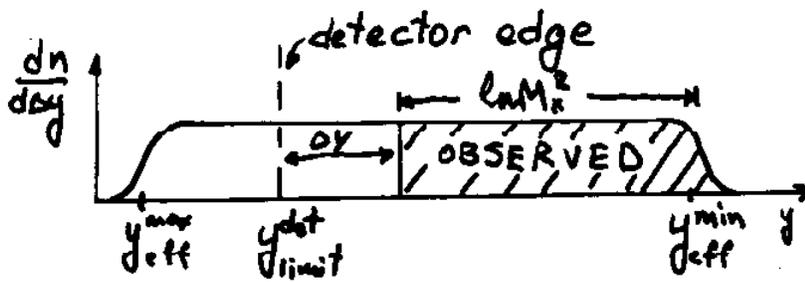
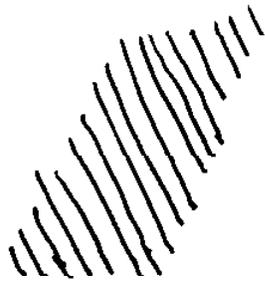
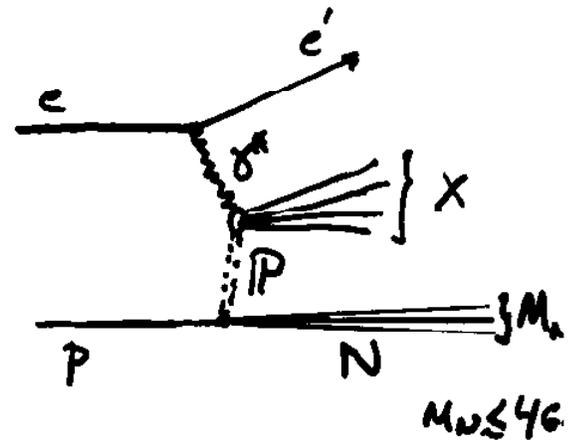
Probability that there are no hadrons in gap $\Delta\eta$ goes as $\sim e^{-a\Delta\eta}$, where a depends on the quantum numbers carried by the gap.

For non-diffractive events probability to have a gap $\sim e^{-a\Delta\eta}$
 For diffractive events ($a \sim 0$) $\sim e^0$

How to extract diffractive signal ?

- require rapidity-gap in a forward region
 1. then need to correct for non-diff contamination by using non-diff MC model
 2. correct for migrations/acceptance by using diffractive MC

Amount of p dissociation depends on rapidity coverage.



$$\Delta y = \ln W^2 / M_x^2 - \underbrace{(y_{\text{det}}^{\text{max}} - y_{\text{det}}^{\text{min}})}_{\text{constant}}$$

$$\text{ND: } \frac{1}{N} \frac{dN}{d \ln W} \equiv P(\Delta y) = \frac{1}{N} \frac{dN}{d \ln M_x^2} = \underline{\underline{c \cdot e^{b \ln M_x^2}}}$$

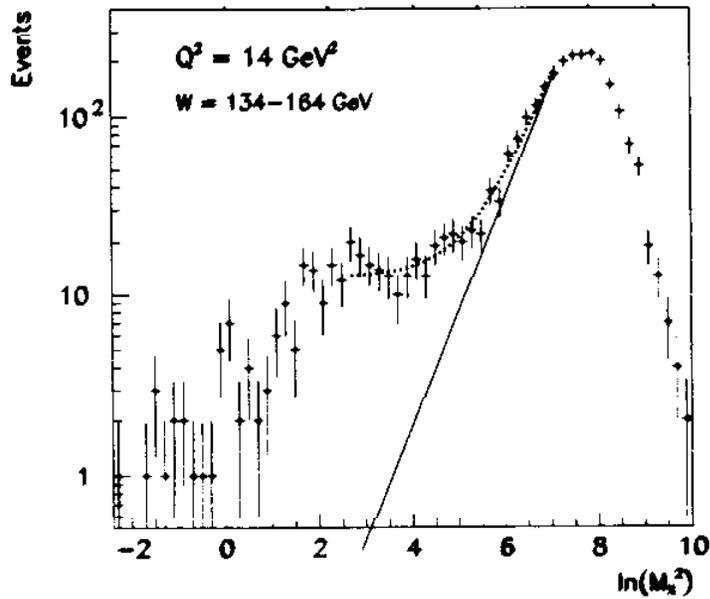
NON-DIFFRACTIVE

← longitudinal phase spac (TOY model) model

Poisson:

$$P(n, \langle n \rangle) = e^{-\langle n \rangle} = e^{-\lambda \Delta y}$$

M_x method:



$$\frac{dN}{d\ln M_X^2} = D + c \cdot \exp(b \ln M_X^2)$$

ZEUS Operational Definition:

Diffraction – Signal above *exponential slope* in $\ln M_x^2$.

Equivalent to the requirement of observing –

not exponentially suppressed rapidity gap Δy in the detector.

Understanding slope with ARIADNE MC.

$$Q^2 = 14 \text{ GeV}^2$$

--- hadron level
— detector level

Events

$$W = 60 - 74 \text{ GeV}$$

fit:
 $c \cdot e^{b \ln M_x^2}$

Events

$\ln M_x^2$

$$W = 110 - 134 \text{ GeV}$$

$\ln M_x^2$

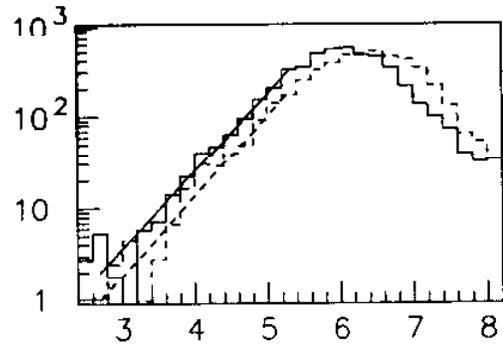
Events

$$W = 164 - 200 \text{ GeV}$$

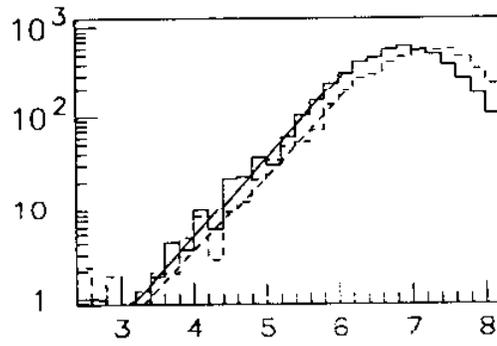
$\ln M_x^2$

- We observe no detector effects on the shape and magnitude of the slope

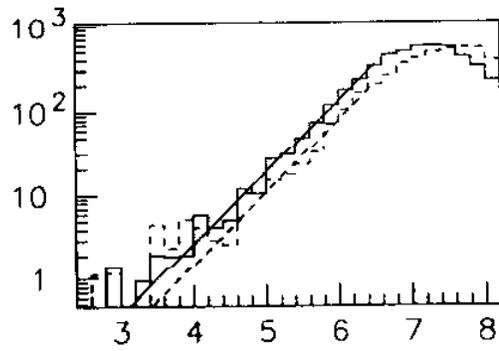
$$b_{\text{hadron}} = b_{\text{detector}}$$



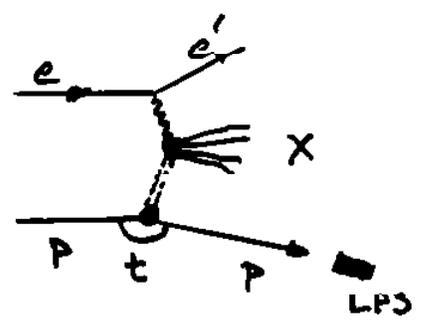
ZUF0s



ZUF0s

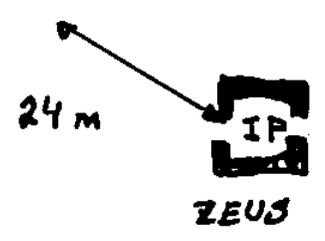


ZUF0s

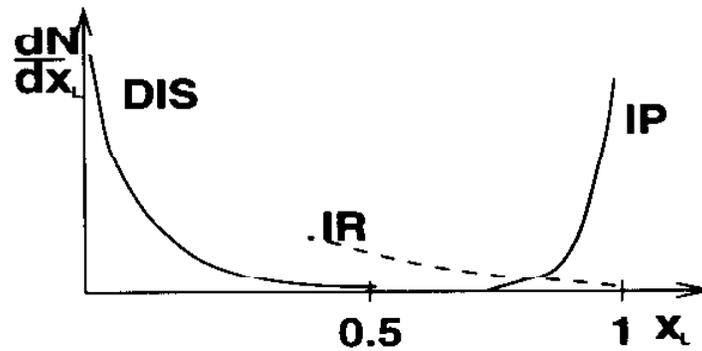


$$\frac{\Delta x_e}{x_e} \approx 0.4\% \text{ @ } x_e \sim 1$$

$\Delta p_t \approx 5 \text{ MeV} \ll \text{beam trans. meas. spread}$



LPS method:



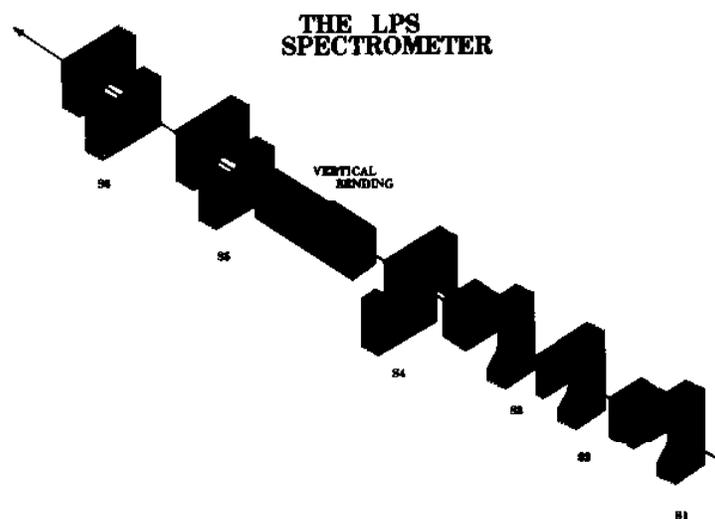
- LPS – Measure leading proton in the final state.

for IP exchange: $x_l = p'_z/p_z \sim 1$.

for non IP exchange: $x_l = p'_z/p_z < 1$.

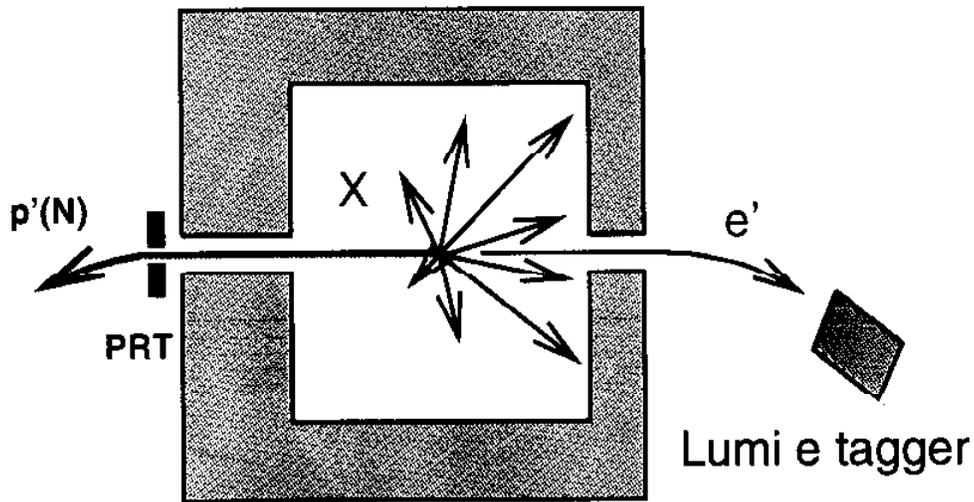
allows measurement of t-slope

p dissociation contribution is small if $x_l > 0.97$



Photoproduction

Rapidity-gap analysis:



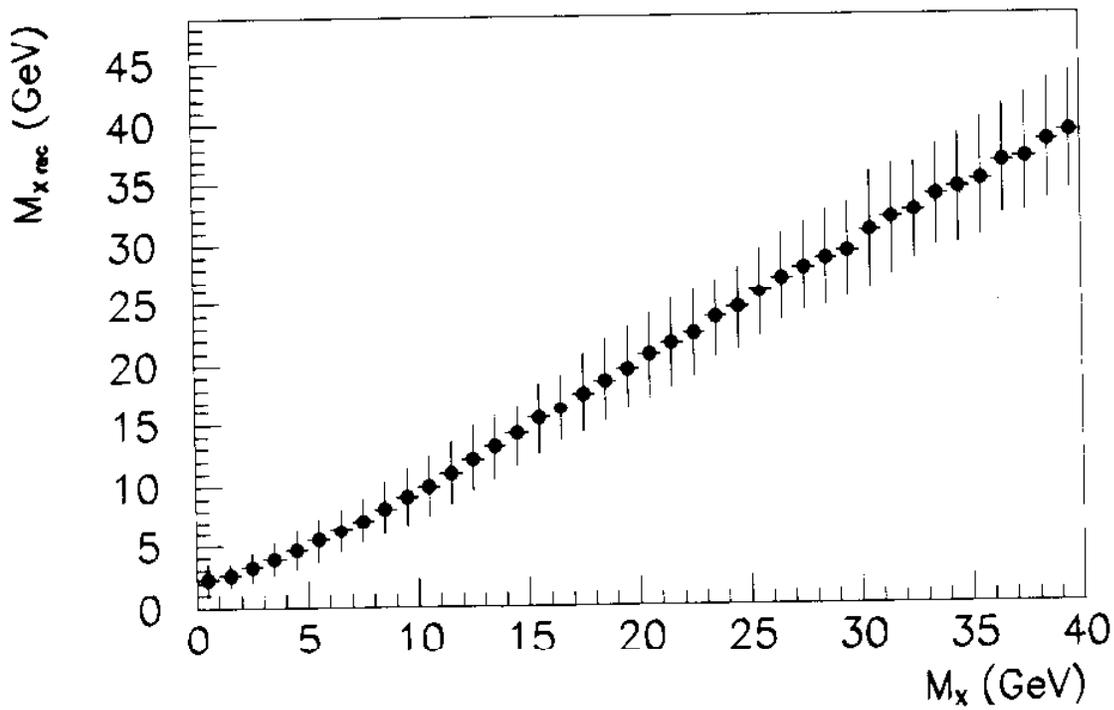
Event selection:

- Lumi e and REMC $\rightarrow (Q^2 < 0.02 \text{ GeV}^2)$
- LUMI energy $12 < E_e < 18 \text{ GeV} \rightarrow 176 < W < 225 \text{ GeV}$
- require rapidity-gap \rightarrow no activity in PRT1 ($4.3 < \eta_{gap} < 5.8$)
- take events where X opens up enough for reliable M_X measurement: $\eta_{max} > -1.5$

M_X reconstruction

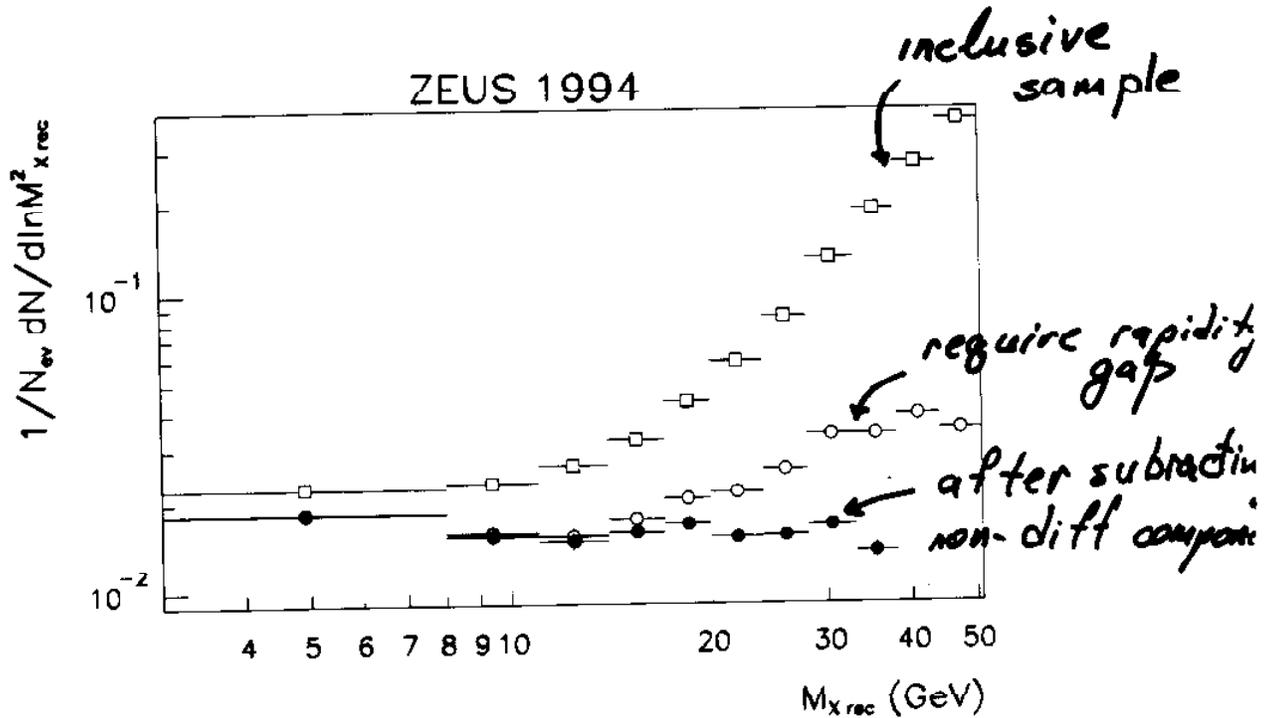
$$M_{X\text{ rec}} = 1.14 \cdot \sqrt{2(E_e - E_{e'}) \cdot \left(\sum_{\text{cond}} E_i + \sum_{\text{cond}} E_i \cos\theta_i \right) + 1.2 \text{ GeV}}$$

Summed over condensates after noise suppression.



- Resolution $\sigma(M_X)/M_X \approx 80\%/\sqrt{M_X}$ for $4 < M_X < 45$ GeV
- In data checked for events with p in LPS:
→ $(M_{X\text{ rec}} - M_{X\text{ LPS}})$ has a Gaussian peak at 0 ± 0.5 GeV

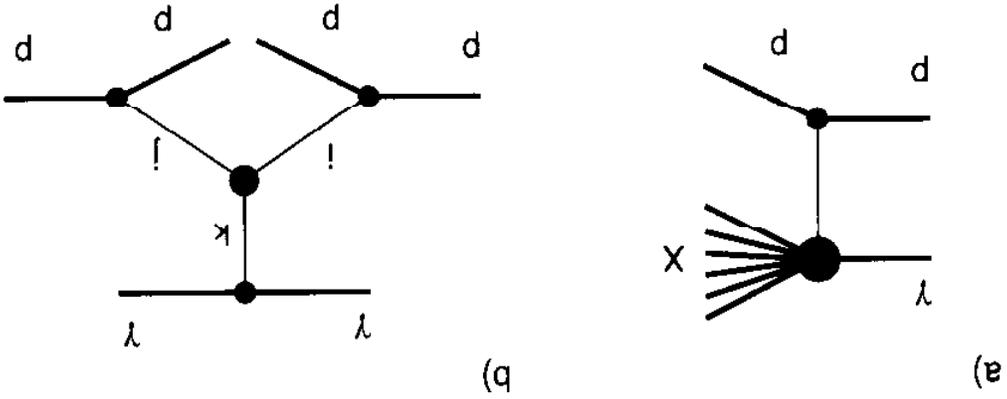
Uncorrected Spectrum



- subtract the non-diffractive component using two alternative MC models: EPSOFT and PYTHIA:
→ for *non-diff background* < 40% stay at $M_X < 24$ GeV
- Corrected for detector effects (using diffractive MC):
trigger acceptance, migration, inefficiencies,
dead material,...

Triple Regge model

Processes related by Mueller's theorem:



In diffractive domain – small M_x^2/W^2 , triple Regge dominates:

$$d^2\sigma/dM_x^2 = \left(\frac{1}{W^2}\right)^2 \cdot \sum_{ijk} G^{ijk}(t) \cdot \left(\frac{M_x^2}{W^2}\right)^{\alpha_i(t)+\alpha_j(t)} M_{\alpha_k(0)}^2$$

Two possible terms describing pomeron exchange:

- $ijk = PPI$ → $d\sigma/dM_x^2 \propto 1/M_x^2$
- $ijk = PPR$ → $d\sigma/dM_x^2 \propto 1/M_x^3$

steeper M_x behavior → may dominate low M_x .

• In this analysis t is not measured (eg. $PIPI$):

$$\frac{dM_x^2}{d\sigma} = \int_{t_{min}}^{t_{max}} d^2\sigma \propto \frac{1}{b_0 + 2\alpha_{PI} M_x^2/W^2} \cdot \left(\frac{M_x^2}{W^2}\right)^{\alpha_{PI(0)}}$$

assuming $\alpha_p = 0.25 \text{ GeV}^{-2}$ and $b_0 = 4 \text{ GeV}^{-2}$.

$$f_{IP}^{IPR} = 26 \pm 3(stat) \pm 12(syst)\%$$

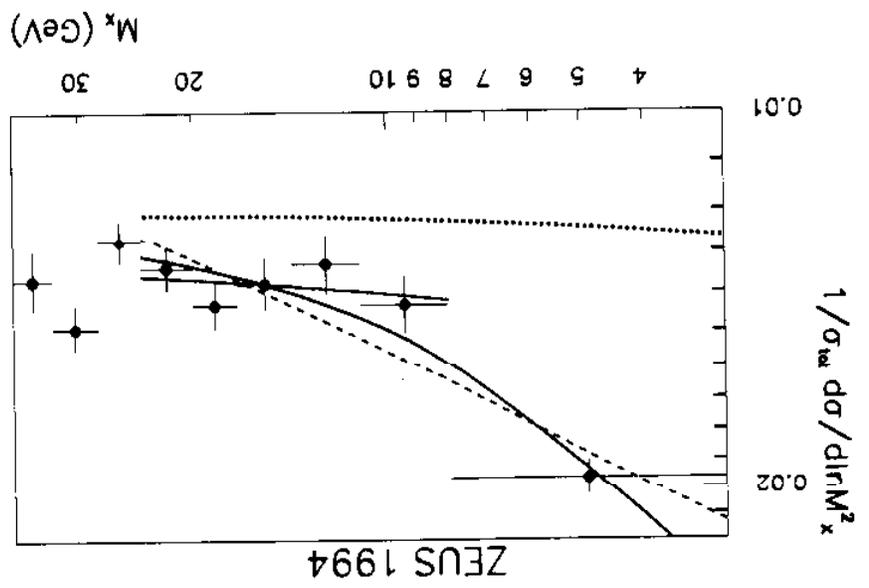
from IP^{IPR} :

- Insufficient lever arm to determine relative contribution and intercepts of the two components.
- Assume $\alpha^{IP}(0) = 1.08$ and $\alpha^{IR}(0) = 0.45$, and fit their relative contributions.
- Fraction of the diffractive cross section in $3 < M_X < 24$ GeV

Try fitting $IP^{IP} + IP^{IPR}$ terms:

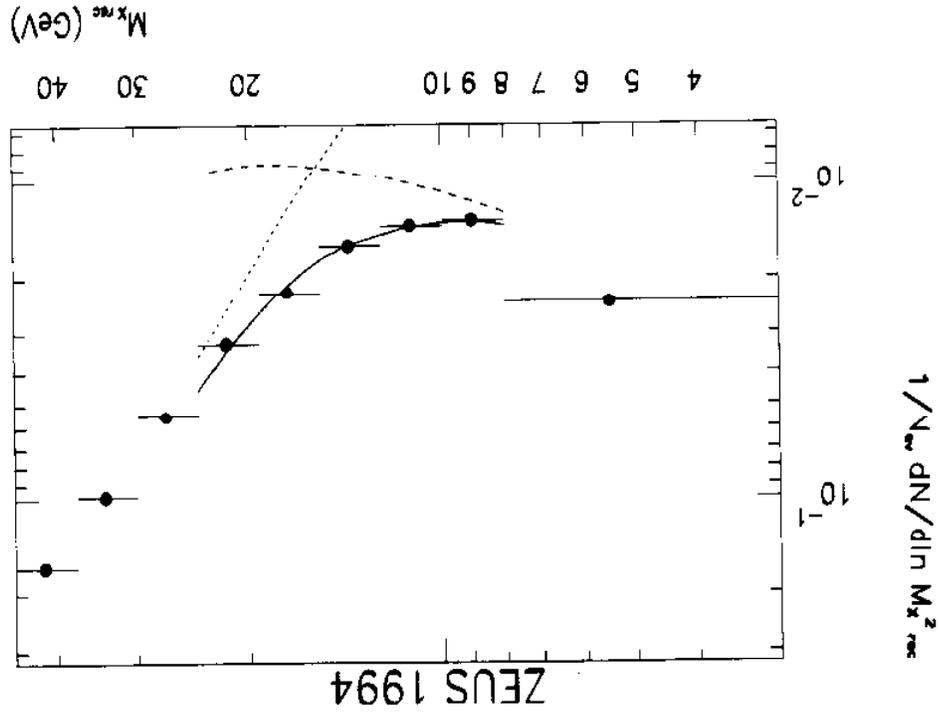
- $\alpha^{IP}(0)$ depends on M_X interval \rightarrow effective $\alpha^{IP}(0)$.
- $3 < M_X < 24$ GeV $\rightarrow \alpha^{IP}(0) = 1.20 \pm 0.02(stat)$ poor fit
- $8 < M_X < 24$ GeV $\rightarrow \alpha^{IP}(0) = 1.12 \pm 0.04(stat) \pm 0.08(syst)$

Fit IP^{IP} term only:



$$\alpha_p(0) = 1.15 \pm 0.08(\text{stat})$$

M_x method analysis:



Fit sum of non-diffractive and diffractive component

$$\frac{1}{\Delta N} \frac{N_{ev} \Delta \ln M_x^2}{\Delta N} = A_{VD} \cdot \frac{1}{\Delta \sigma_{VD}} \frac{\sigma_{tot} \Delta \ln M_x^2}{\Delta \sigma_D} + A_D \cdot \frac{1}{\Delta \sigma_D} \frac{\sigma_{tot} \Delta \ln M_x^2}{\Delta \sigma_D}$$

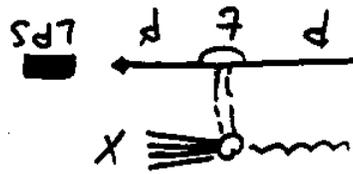
A_{VD}, A_D = correction factors \Rightarrow acceptance, migrations etc. calculated with NZ MC for diffractive and EPSOFT for non-diffractive.

Triple Pomeron formula assumed for diffractive component.

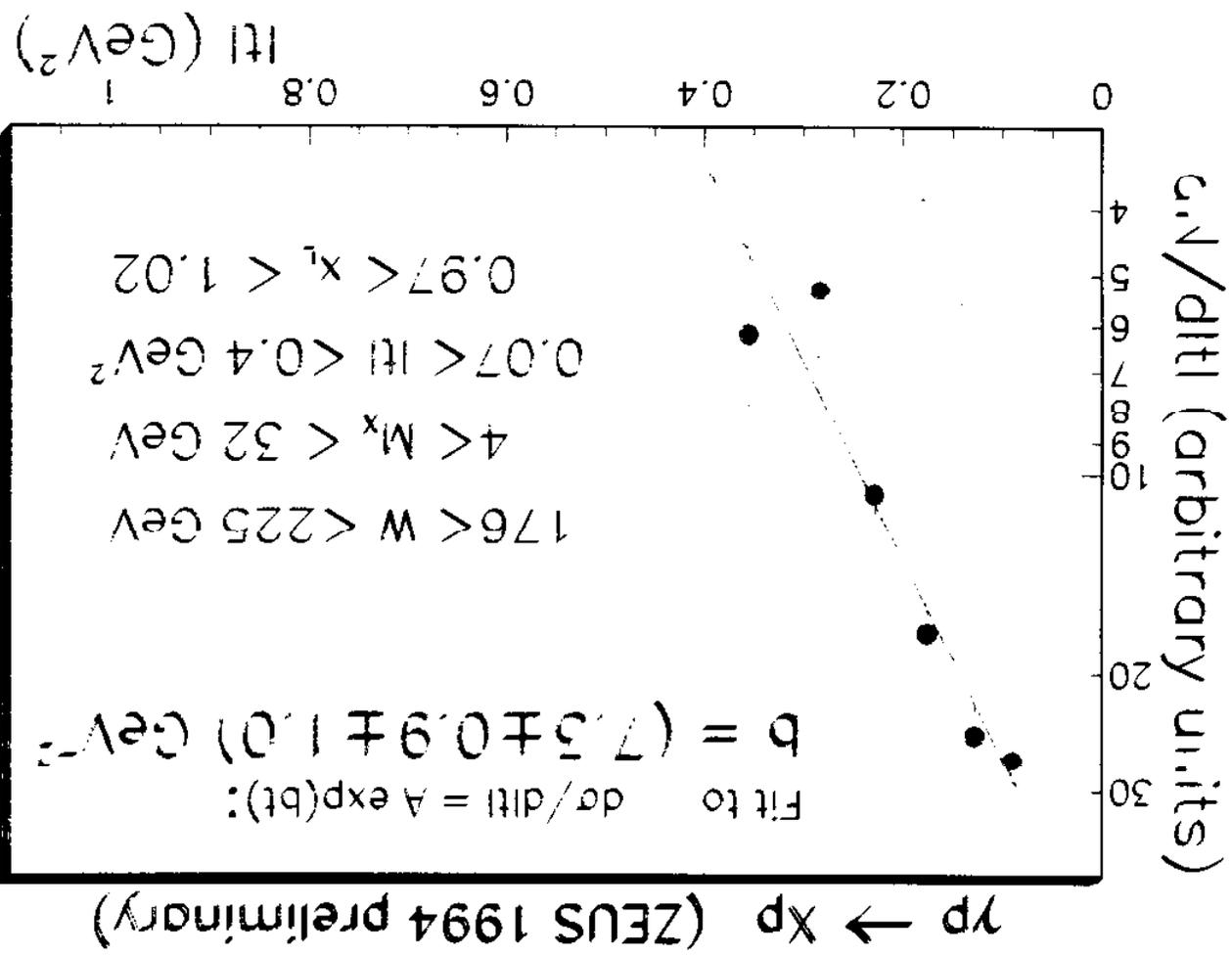
Non-diffractive component parameterized as $\exp(b \ln M_x^2)$.

Fit performed in the range $8 < M_x < 24 \text{ GeV}$

Measurement of the τ slope
in Photoproduction



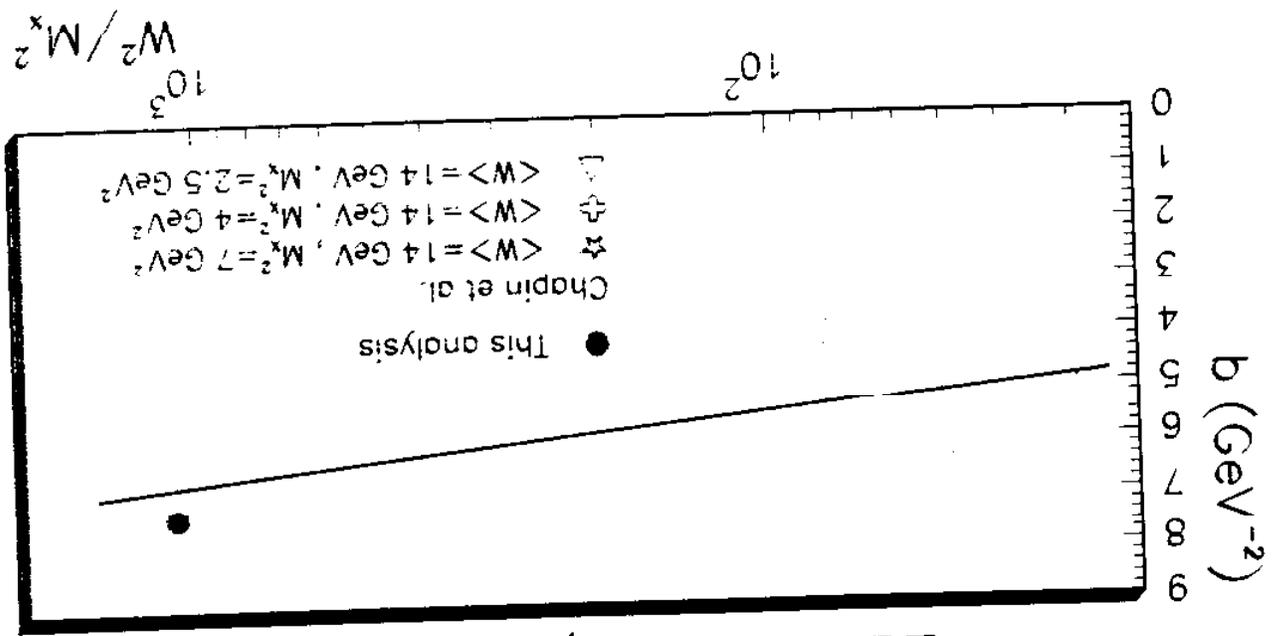
$$\tau \text{ measured as: } \tau = \frac{-A_1}{A_2} X_e$$



where $\alpha' = 0.25$ and normalization was adjusted to low energy data.

$$b = b_0 + 2\alpha' \ln\left(\frac{M_x}{M_0}\right)$$

ZEUS 1994 preliminary



Conclusions from Photoproduction Measurement

- We measured $d\sigma/dM_X^2$ in photoproduction at $W_{\gamma p} \approx 200$ GeV
- Primary analysis: rap-gap to identify diffractive processes; Confirmed by analysis relying on shape of m_{Δ}^2

- Diffractive $\gamma p \rightarrow X_N, 3 < M_X < 24$ GeV, $M_N < 2$ GeV:

$$\frac{\sigma_{\text{tot}}^D}{\sigma_{\text{tot}}} = 0.2 \pm 0.2(\text{stat}) \pm 1.3(\text{syst})\%$$

- Single diffractive, $\gamma p \rightarrow X_p, m_0 < M_X < \sqrt{0.05W^2}$:

$$\sigma_{\text{tot}}^D \sigma_{\text{tot}} = 13.3 \pm 0.5(\text{stat}) \pm 3.6(\text{syst})\%$$

- In $8 < M_X < 24$ GeV data may be parameterized by triple-pomeron formula with $\alpha_{\mathbb{P}}(0) = 1.12 \pm 0.04(\text{stat}) \pm 0.08(\text{syst})$.
- A significant excess of diffractive events at $3 < M_X < 8$ GeV over the level expected from the triple pomeron relation.

- Excess is consistent with $\mathbb{P}\mathbb{P}\mathbb{P}$ contribution:

assuming $\alpha_{\mathbb{P}}(0)$ and $\alpha_{\mathbb{H}}(0)$ derived from fits to total and elastic hadronic cross section the $\mathbb{P}\mathbb{P}\mathbb{P}$ term is responsible for $26 \pm 3(\text{stat}) \pm 12(\text{syst})\%$ of cross section in $3 < M_X < 24$ GeV, similar to results from proton dissociation at lower energy.

- t distribution for the reaction $\gamma p \rightarrow X p$ has been measured. The distribution exhibits an exponential shape with a slope parameter $b = 7.3 \pm 0.9(\text{stat}) \pm 1.0(\text{syst}) \text{GeV}^{-2}$

Diffraction in DIS

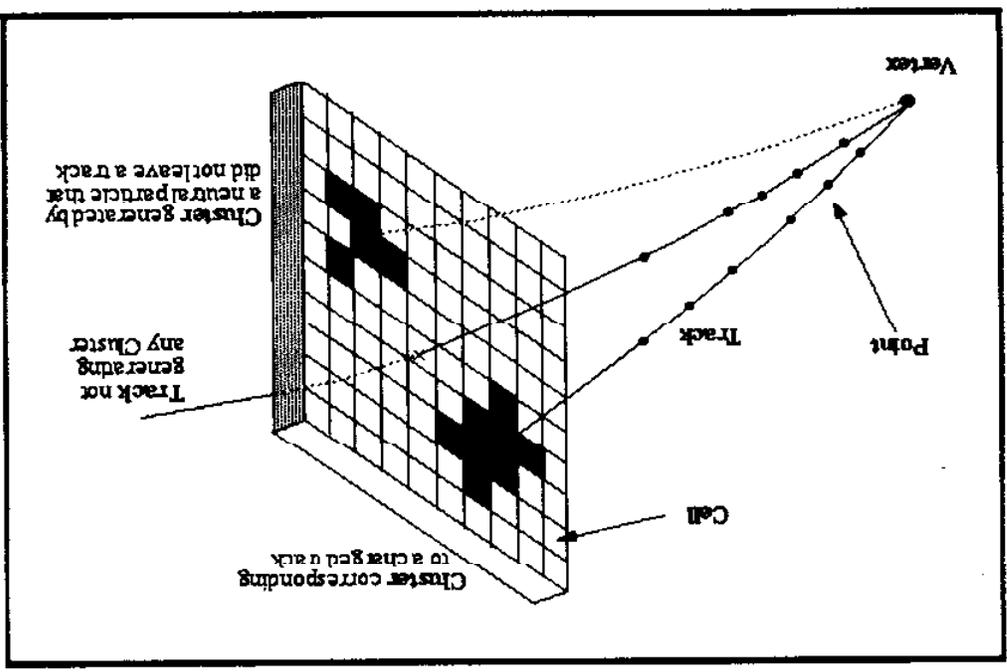
Different from previous analysis ('93 data):

- In 1994 we collected 5 times more luminosity:
 $\rightarrow L_{94} = 2.61 \text{ pb}^{-1}$
- Improved M_x reconstruction by combining information from CAL and CTD $\rightarrow \sigma(M_x)/M_x = 64\%/\sqrt{M_x}$
- Extended Q^2 range: $7 \leftrightarrow 140 \text{ GeV}^2$
- Added MC generator
- RapGap – interfaced with Heracles for radiative effects.

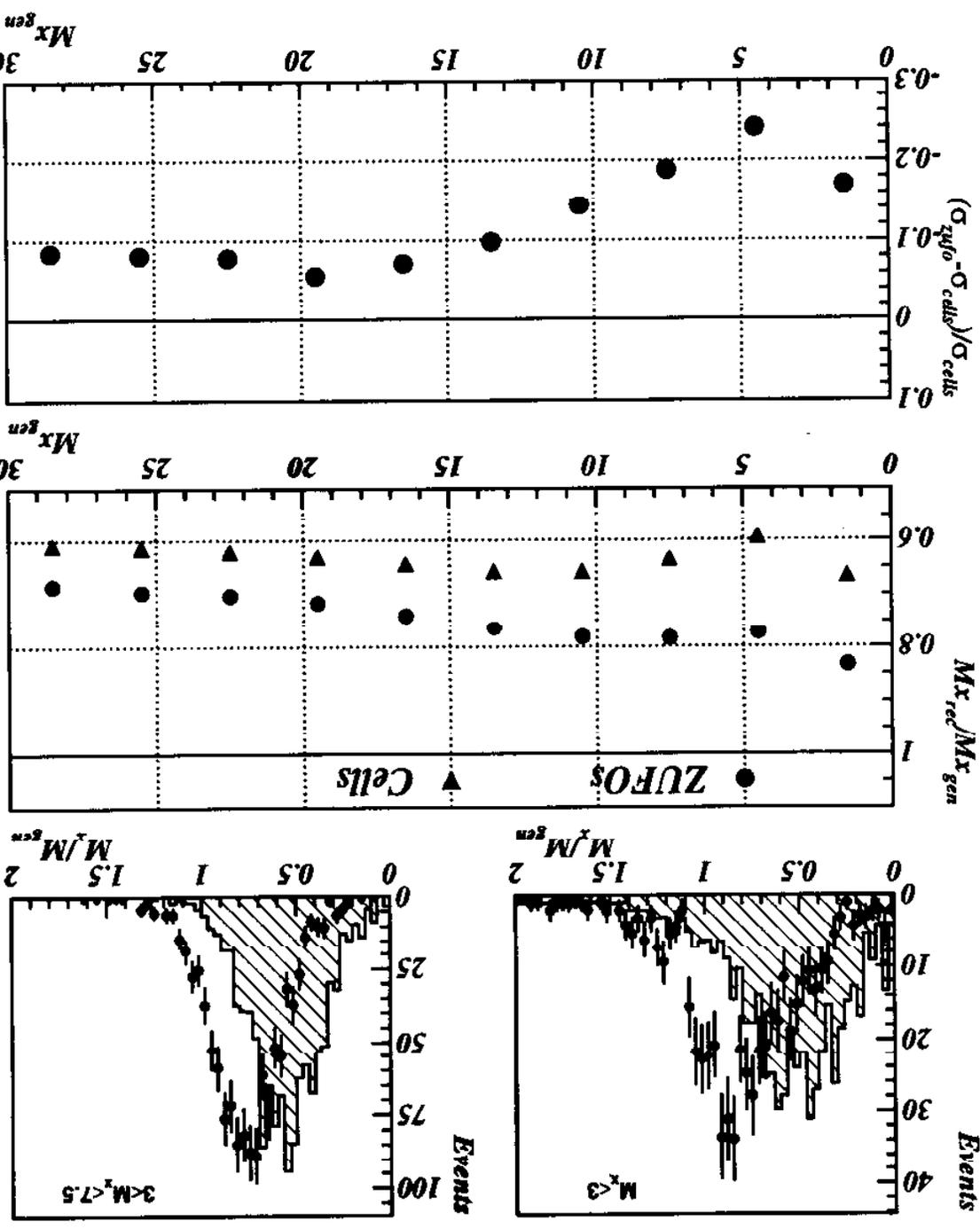
- Common Problems in Mix reconstruction using only Calorimeter information.

1. Energy resolution and energy shift due to dead material
2. Limits in position resolution due to coarse granularity of CAL
3. Missing low energy charged particles in the central region.

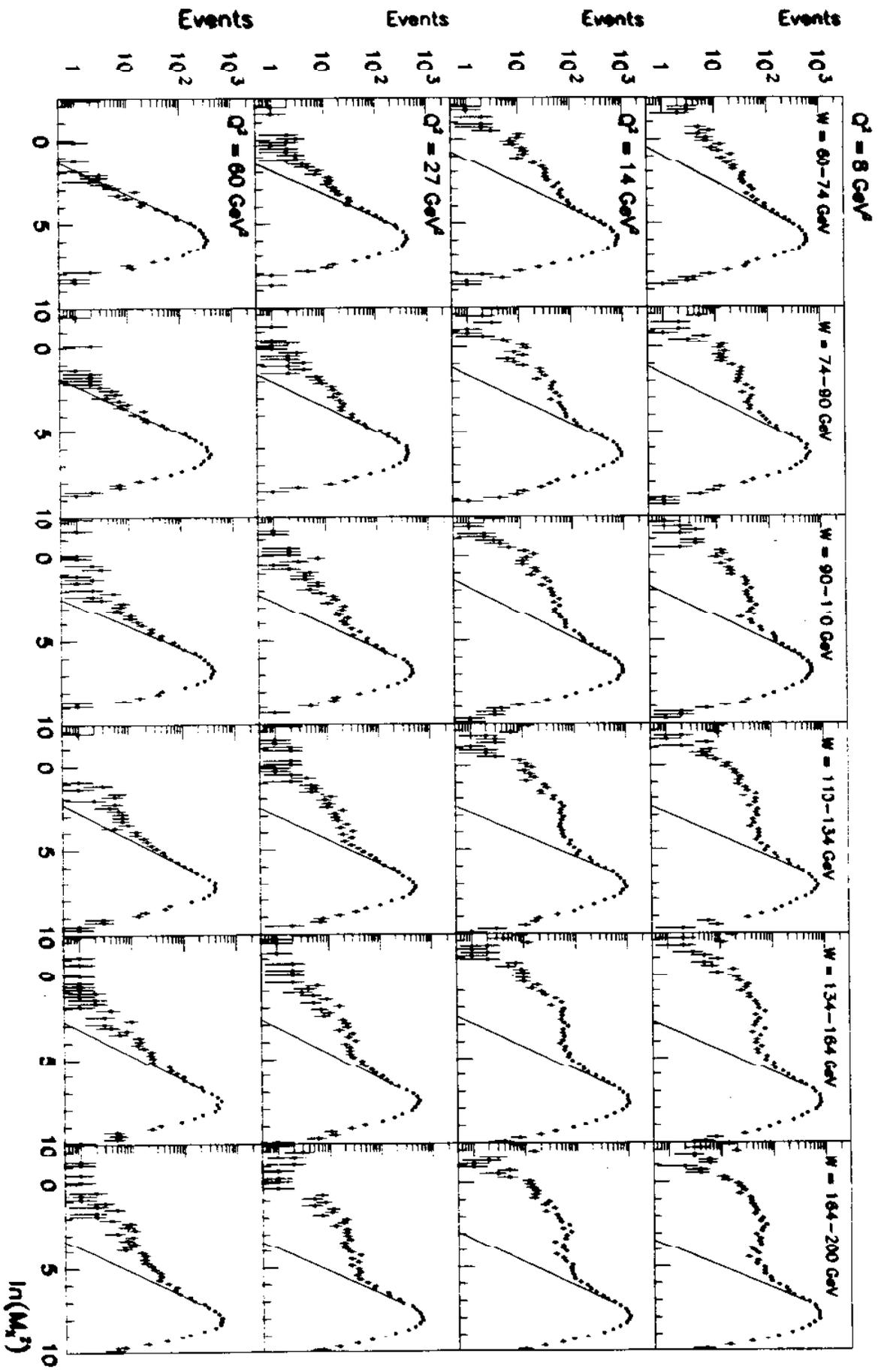
- Solution:
 - Combine information from Calorimeter and tracking.



Mass Reconstruction - Diffractive DIS MC (RapGap)



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DIS Xsection becomes diffractive Xsection after the non-diffractive background was removed.

NOTE: DIS-Xsections $d\sigma/dM_x d\ln W^2 dQ^2$ or $d\sigma/dp dX_p dQ^2$ are not automatically diffractive

$$F_{DIS}^2 = \frac{4\pi^2 \alpha^2 W^2}{Q^2 (W^2 + Q^2)} \frac{d\sigma_{DIS}^{(p)}}{dM_x}$$

$\frac{d\sigma_{DIS}^{(p)}}{dM_x}$ EQUIVALENT TO $F_{DIS}^2(s, X_p, Q^2)$

$$\frac{d\sigma_{DIS}^{(p)} \rightarrow eXU}{d\beta dX_p dQ^2} = \frac{2\pi \alpha^2}{\beta \cdot Q^4} [(1-\beta)^2 + 1] F_{DIS}^2(s, X_p, Q^2)$$

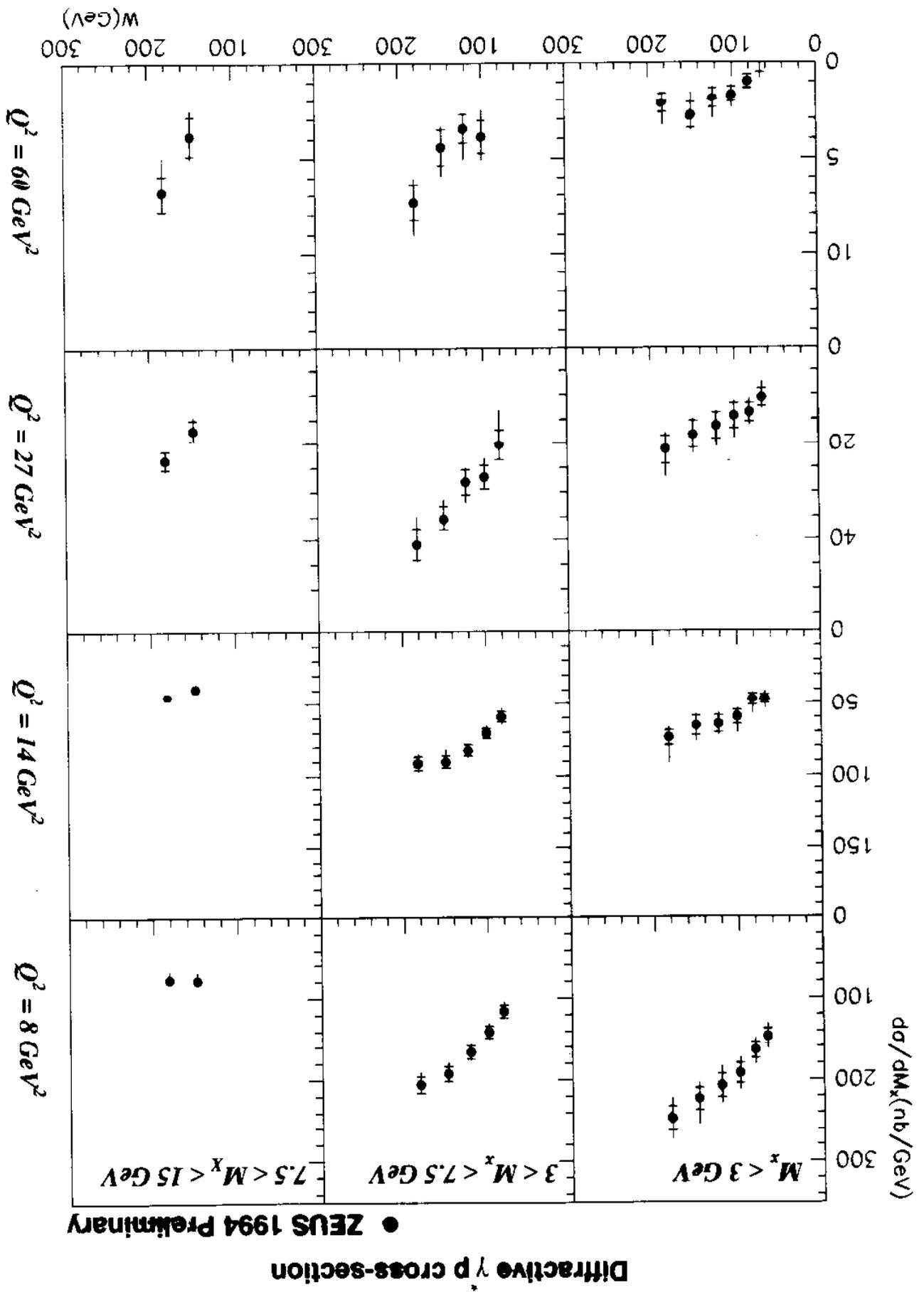
MEASURE EXTRACT

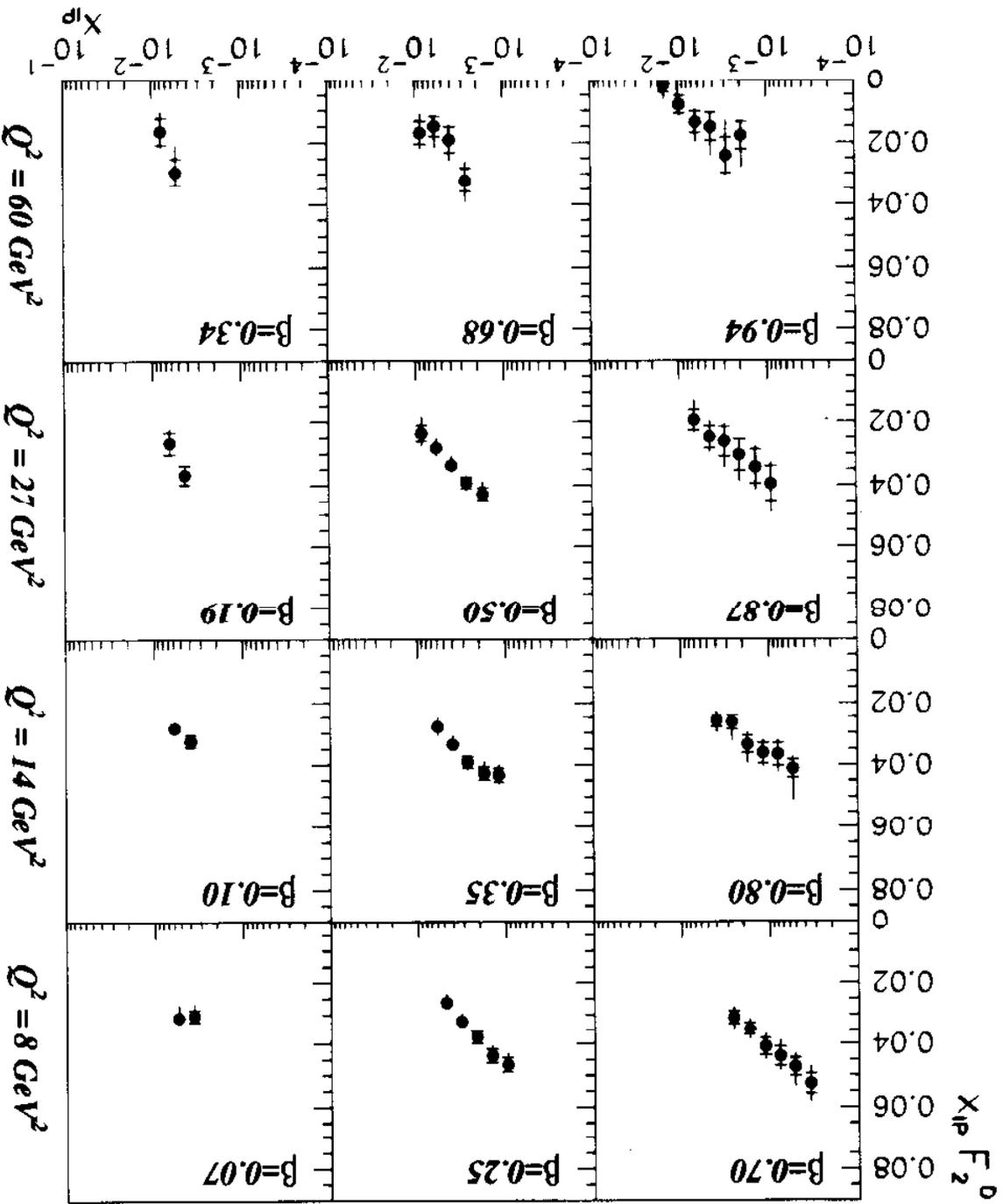
In terms of structure function:

neglected term: $\frac{Q^2}{A^2} \frac{(1-\beta)^2 + 1}{Q^2 + Q^2}$

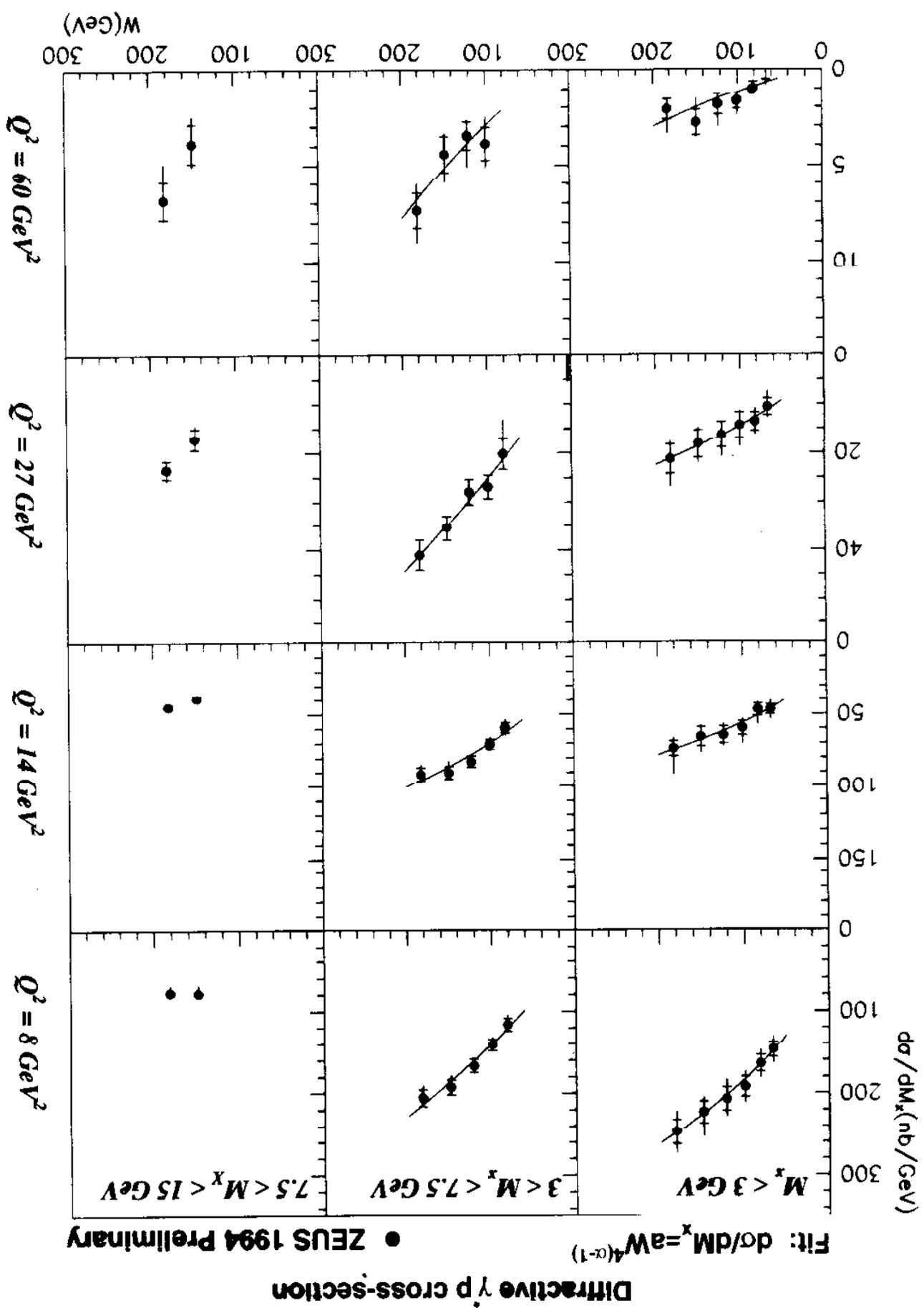
$$Q^2 \frac{d\sigma_{DIS}^{(p)} \rightarrow eXU}{dM_x d\ln W^2 dQ^2} \approx \frac{2\pi}{\alpha} [(1-\beta)^2 + 1] \frac{d\sigma_{DIS}^{(p)}}{dM_x} (W, Q^2, M_x)$$

MEASURE EXTRACT





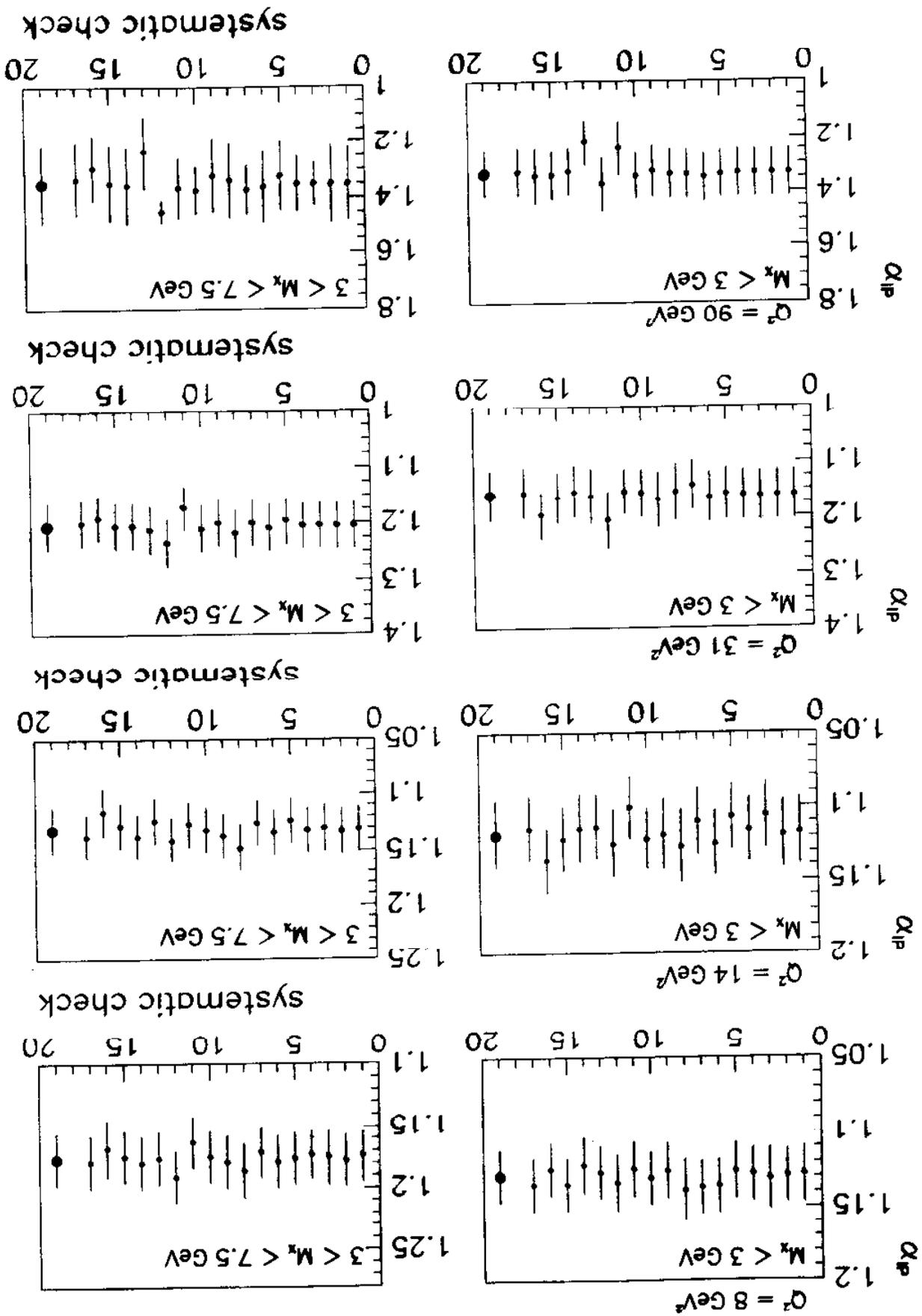
• ZEUS 1994 Preliminary



Systematic checks

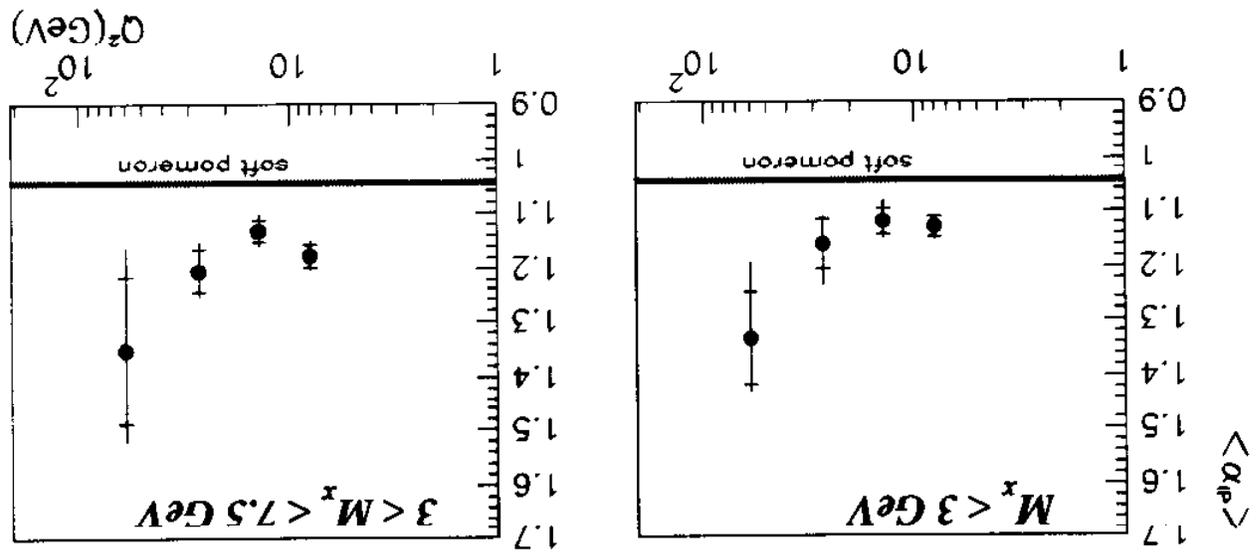
11,21	-	Raise/lower	electron energy 12/8 GeV
13,41	-	Raise/lower	box cut 15/11 cm
15,61	-	Raise/lower	E-p ₂ cut 42/98
17,81	-	Raise/lower	η cut 0.03/0.01
19,101	-	Energy scale	MC/data mismatch by 10%
11	-	Tight vertex cut	
12,131	-	Raise/lower	slope end point
14,151	-	MC weighting	systematic
16	-	USE Rimpuff	for unfolding
17	-	Higher noise suppression	180/200 (cm ²)

ZEUS 1994 Preliminary



ZEUS diffractive cross sections are not compatible with the Donnachie-Landshoff Soft Pomeron (more data needed)

there is a tendency for α_{ip} to grow with Q^2 (GeV)



● ZEUS 94 (preliminary)

Conclusion

- Photo production $\frac{d\sigma}{dM_x^2}$ at $W_p = 200 \text{ GeV}$

In $8 < M_x < 32 \text{ GeV}$ data may be parametrized by triple-pomeron formula with $\alpha_p(0) = 1.125 \pm 0.047$ and

In $4 < M_x < 32 \text{ GeV}$, $0.07 < t < 1 \text{ GeV}^2$ and $0.97 < x_e < 1.02$, the $b = 7.3 \pm 0.9 \pm 1.0 \text{ GeV}^{-2}$

Both results are consistent with soft pomeron.

The rapidity-gap method and M_x method give the same result.

- DIS In DIS we have measured $\frac{d\sigma_{\text{DIS}}}{dM_x^2}$, $M_x \leq 4 \text{ GeV}$

as a function of W in bins of M_x and Q^2 in the range $200 < M_x < 15 \text{ GeV}$, $60 < W < 200 \text{ GeV}$ and $8 < Q^2 < 140 \text{ GeV}^2$ and we find that α_p is not compatible with soft pomeron.

We also observe a tendency for α_p to grow with $Q^2 \text{ GeV}^2$, but more data is needed.